MESON SPECTRA FROM AN EFFECTIVE LIGHT CONE QCD-INSPIRED MODEL

Shan-Gui Zhou

Max-Planck-Institut für Kernphysik, 69029 Heidelberg, Germany

School of Physics, Peking University, Beijing 100871, China

Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, China

Center of Theoretical Nuclear Physics, National Lab. of Heavy Ion Accelerator, Lanzhou 730000, China

Abstract

I present some recent applications of a light cone QCD-inspired model with the mass squared operator consisting of a harmonic oscillator potential as confinement in the meson spectra. The model gives an universal and satisfactory description of both singlet and triplet states of S-wave mesons. In the present work P-wave D_s mesons are also investigated. The mass of the recently found meson, $D_{sJ}^*(2317)^+$ is reproduced fairly well by this simple model.

1. INTRODUCTION

In the effective light cone QCD theory [1, 2] the lowest Fock component of the hadron wave function is an eigenfunction of an effective mass squared operator with constituent quark degrees of freedom and parameterized in terms of an interaction which contains a Coulomb-like potential and a Dirac-delta term. All higher Fock-state components of the hadron light-front wave function can be constructed recursively from the lowest one. The interaction in the mass operator comes from an effective one-gluon-exchange where the Dirac-delta term corresponds to the hyperfine interaction.

The masses of the ground state of the pseudoscalar mesons and in particular the pion structure [3] were described reasonably, with a small number of free parameters, which is only the canonical number plus one—the renormalized strength of the Dirac-delta interaction. This model was also extended to include the confining interaction and used to study the S-wave meson spectra universally [4, 5]. In the light cone framework (mass squared operator appears in the Hamiltonian), the confining harmonic oscillator potential gives a natural explanation of the observation of an almost linear relationship between the mass squared of excited states with radial quantum number n [6]. We note that quite recently, another harmonic oscillator approach was also used in the description of scalar mesons successfully [7].

Recently a new narrow resonance $D_{sJ}^*(2317)^+$ was observed by the BABAR Collaboration [8] and confirmed by the CLEO Collaboration [9]. Both the small mass and the small width are in conflict with predictions of many models [10, 11, 12]. Since then much discussion has been made concerning this new meson state. Some authors suggest that it is a four quark meson [13]. Many others argue that it is still within the normal picture of meson, namely, consisting of two constituent quarks [14]. The effective light cone Hamiltonian model—the light cone harmonic oscillator (LCH) model proposed in [4, 5] was also applied to this new meson [15]. The mass of $D_{sJ}^*(2317)^+$ could be reproduced quite accurately by the LCH model without changing the parameters fixed previously.

The details of the application of this model in S-wave mesons were published in [4, 5]. In the present paper, I will concentrate on P-wave D_s mesons. Compared to [15], a more reasonable spin-orbit interaction was adopted here. In section 2., I briefly review the formalism of this model. The discussion on $D_{sJ}^*(2317)^+$ is presented in section 3.. Finally I will give a summary.

2. THE LIGHT CONE HARMONIC OSCILLATOR MODEL

In the effective light cone QCD theory the bare mass operator equation for the lowest Fock-state component of a bound system consisting of a constituent quark and antiquark with masses m_1 and m_2, is

Table 1: Parameters for the light cone harmonic oscillator model. c_0 and c_2 of the harmonic oscillator potential and the masses of up, down and charm quarks are fixed from the masses of $\rho(770)$, $\rho(1450)$, $J/\psi(1S)$ and $\psi(2S)$ [18], with the assumption of $m_u = m_d$. Strange and bottom quark masses are determined by the masses of K^* and B^* [18].

Parameters	c_0 [MeV]	c_2 [GeV^3]	$m_u = m_d$ [MeV]	m_s [MeV]	m_c [MeV]	m_b [MeV]
Values	807	0.0713	265	478	1749	5068

described as [1, 2]

$$
M^2 \psi(x, \vec{k}_\perp) = \left[\frac{\vec{k}_\perp^2 + m_1^2}{x} + \frac{\vec{k}_\perp^2 + m_2^2}{1 - x} \right] \psi(x, \vec{k}_\perp)
$$
$$
- \int \frac{dx' d\vec{k}_\perp' \, \theta(x')\theta(1 - x')}{\sqrt{x(1 - x)x'(1 - x')}} \left(\frac{4m_1 m_2}{3\pi^2} \frac{\alpha}{Q^2} - \lambda - W_{\text{conf}}(Q^2) \right) \psi(x', \vec{k}_\perp') , \quad (1)
$$

where M is the mass of the bound-state and ψ is the projection of the light-front wave-function in the quark-antiquark Fock-state. The confining interaction is included in the model by $W_{\text{conf}}(Q^2)$. The momentum transfer Q is the space-part of the four momentum transfer and the strength of the Coulomb-like potential is α. The singular interaction is active only in the pseudoscalar meson channel with λ as the bare coupling constant.

The mass operator equation could be transformed to the instant form representation [16] and further simplified by omitting the Coulomb term to the form [4, 5]

$$
\left(M_{\text{ho}}^2 + g\delta(\vec{r}) \right) \varphi(\vec{r}) = M^2 \varphi(\vec{r}) , \quad (2)
$$

where the bare strength of the Dirac-delta interaction is g, and the mass squared operator is

$$
M_{\text{ho}}^2 = 2m_t \left(-\frac{\vec{\nabla}^2}{2m_r} + \frac{1}{2}m_t - c_0 + \frac{1}{2}c_2 r^2 + \kappa \vec{L} \cdot \left[\frac{\vec{\sigma}_1}{m_1^2} + \frac{\vec{\sigma}_2}{m_2^2} \right] \right) , \quad (3)
$$

where $m_t = m_1 + m_2$ and $m_r = m_1 m_2/(m_1 + m_2)$. The harmonic oscillator potential is introduced as a confinement with c_0 and c_2 being two universal parameters valid for all mesons. The phenomenological spin-orbit term [10] is included for $L \neq 0$ states which is zero for S-wave states and was omitted in [4, 5]. Note that in [15] we used a much simpler spin-orbit interaction which also gives reasonable results for $D_{sJ}^*(2317)^+$. The eigenvalue of M_{ho}^2, i.e., the mass squared of a vector meson or a $L \neq 0$ meson, is given by

$$
M_{nLJ}^2 = 2m_t \left[\left(2n + L + \frac{3}{2} \right) \sqrt{\frac{c_2}{m_r}} + \frac{1}{2}m_t - c_0 + E_{LJ} \right], n = 0, 1, 2, \cdots . \quad (4)
$$

where E_{LJ} gives the spin-orbit splitting.

For pseudoscalar mesons, the Dirac-delta interaction is active thus the Hamiltonian must be renormalized. One of the renormalization approaches is the T matrix method [17]. The details is found in [4, 5].

The parameters used in the present model are listed in Table 1. The model was first applied to study the pseudoscalar-vector splittings in the S-wave meson spectra [4]. In [5] it was used to investigate the S-wave meson spectra from π-ρ to η_b-Υ and to predict top quark meson spectra. The following conclusions were drawn: (i) the splitting between the light pseudoscalar and vector meson states is due to the strong short range attraction in the $^1S_0$ sector; (ii) the linear relationship between the mass squared of excited states with radial quantum number [6] is apparent from our model and is found to be qualitatively valid even for heavy mesons like Υ; (iii) for the S-wave meson spectra from π-ρ up to η_b-Υ, the simple

Table 2: Masses of P-wave $c\bar{s}$ meson states. The data for $^3P_2$ and $^1P_1$ are taken from [18] and that for $^3P_0$ from [8, 9]. Predictions from [11, 12] are also included for comparison. For the labels of each state, n is the radial quantum number, L the total orbital angular momentum, S the total spin and J the total angular momentum. The second row gives the notation given in [12] where j is the total angular momentum of the strange quark which is conserved in the limit of large charm quark mass. In the present work, the mass of $^3P_2$ (included in a square braket) is used to fix the parameter for the spin-orbit coupling.

$n^{2S+1}L_J$	$n^j L_J$	Data	Ref. [11]	Ref. [12]	This work
0^3P_2	$0^{3/2}P_2$	2.573	2.59	2.581	[2.573]
0^1P_1	$0^{3/2}P_1$	2.536	2.55	2.535	2.517
0^3P_1	$0^{1/2}P_1$	—	2.55	2.605	2.387
0^3P_0	$0^{1/2}P_0$	2.317	2.48	2.487	2.327

model presents satisfactory agreement with available data and/or with the meson mass spectra given by Godfrey and Isgur [10]. Therefore, the extension of the light cone QCD-inspired model which includes a quadratic confinement while keeping simplicity and renormalizability, gives a reasonable picture of the spectrum of both light and heavy mesons.

3. APPLICATION OF THE LCH MODEL TO THE RESONANCE $D^*_{sJ}(2317)^+$

A recent experiment by the BABAR collaboration observes a new narrow $c\bar{s}$ state, $D^*_{sJ}(2317)^+$ with the invariant mass $M = 2.317\,\text{GeV}/c^2$ [8]. Later on this meson is confirmed by the CLEO Collaboration [9]. This state has a natural spin-parity and the low mass suggests a $J^\pi = 0^+$ assignment. In the convention of the quark model, correspondingly, $L = 1$, $S = 1$ and $J = 0$, i.e., $^{2S+1}L_J = {}^3P_0$. The mass of this state is typically predicted between 2.4 and 2.6 GeV/c^2 in [10, 11, 12] (cf. Table 2). In this section, we'll apply the light cone harmonic oscillator model to this and other P-wave D_s mesons.

For $L \neq 0$ states, we include phenomenologically a spin-orbit term as shown in (3) where the strength for the spin-orbit interaction κ is an additional parameter to be determined by the data. For P states, the spin-orbit splitting is derived as

$$E_{LJ} = \kappa \left(\frac{1}{m_1^2} + \frac{1}{m_2^2} \right) \times \begin{cases} \frac{1}{2}, & \text{for } {}^3P_2, \\ \frac{1}{4}\left(-1 + \sqrt{1 + 2\beta^2}\right), & \text{for } {}^1P_1, \\ \frac{1}{4}\left(-1 - \sqrt{1 + 2\beta^2}\right), & \text{for } {}^3P_1, \\ -1, & \text{for } {}^3P_0, \end{cases} \tag{5}$$

where $\beta = (m_1^2 - m_2^2)/(m_1^2 + m_2^2)$. Contrary to [15], the spin orbit interaction in (3) mixes the singlet and triplet states with the same total angular momentum J when $m_1 \neq m_2$. Therefore the two $J = 1$ states, $^1P_1$ and $^3P_1$ from the pure LS coupling scheme mix with each other. The larger the difference between the two constituent masses, the farther $^1P_1$ and $^3P_1$ depart from each other.

The mass of $D_s(^3P_2)$, 2.573 GeV [18] is used to determine the parameter $\kappa = 0.03842$ GeV^3. The masses of the other three P states are easily calculated from Eqs. (4) and (5) and given in Table 2 where predictions from [11, 12] are also included for comparison.

The LCH model reproduces the available data very well. The data are available for other two P-wave $c\bar{s}$ states except $D_s(^3P_2)$ the mass of which is used to determine the parameter κ for the spin-orbit interaction. The calculated $^1P_1$ mass deviates from the datum by only 0.019 GeV. Remarkably, the present prediction for the mass of the lowest P state $D^*_{sJ}(2317)^+$ is in good agreement with the experimental value. Therefore from our model, $D^*_{sJ}(2317)^+$ might still be a "normal" meson consisting of two constituent quarks which agrees with our previous conclusion [15] and many other recent works [14].

4. SUMMARY

We applied the light cone harmonic oscillator (LCH) model—a renormalized light cone QCD-inspired effective theory with a quadratic confinement in the mass squared operator—to study the meson spectra.

The model was applied to the S-wave mesons from π-ρ up to η_b-Υ [4, 5]. In this model, the splitting between the light pseudoscalar and vector meson states is due to the strong short range attraction in the $^1S_0$ sector. The linear relationship between the mass squared of excited states with radial quantum number [6] is naturally explained. This model presents reasonable agreement with available data.

The P states of the charmed strange meson are investigated by using the LCH model with a phenomenological spin-orbit interaction included (cf. [15]). The mass of the recently found meson, $D_{sJ}^*(2317)^+$ [8, 9] could be reproduced quite well by this simple model.

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